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Influence of Planting Techniques and Integrated Nutrient Management on Soil Health in Rice (*Oryza sativa* L.)

G. Naveen Kumar [a*], P. K. Singh [a] and R. K. Naresh [a]

[a] Department of Agronomy, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, Uttar Pradesh, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The study investigated the impact of different planting techniques and nitrogen management at Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut (UP) during the rainy (*kharif*) season of 2019-20 on soil health in rice. Soil samples were collected at two depths, air-dried, and analyzed for aggregate size distribution using wet sieving. Particulate organic carbon (POC) was determined through aggregate slaking, while total organic carbon (TOC) content was assessed using rapid titration. Microbial biomass carbon (MBC) was calculated by incubating soil samples, followed by fumigation-extraction methods. Results revealed that soil pH and electrical conductivity remained unaffected by planting techniques and fertility levels. Aggregate size distribution analysis revealed that the Furrow Irrigated Raised Bed (FIRB) treatment promoted larger macro-aggregates (>2mm) at varying soil depths, while Conventional Tillage (CT) encouraged smaller micro-aggregates. Reduced Tillage (RT) combined with Farmyard Manure (FYM) and chemical fertilizer increased POC and TOC content, emphasizing the importance of reduced soil disturbance and organic matter addition. Conversely, CT exhibited lower POC and TOC levels due to intensive soil disturbance. RT with FYM and chemical fertilizer significantly enhanced soil MBC, highlighting their role in improving soil health and fertility.

**Corresponding author: E-mail: gundlapallinaveen26@gmail.com;*

Keywords: Farm yard manure; macro aggregates; micro aggregates; microbial biomass carbon; planting techniques.

1. INTRODUCTION

India is the world's second-largest producer and consumer of rice. With a yield of 2.57 tonnes ha^{-1} and a production rate of 112.76 million tonnes, rice is cultivated on 43.77 million hectares in India. Uttar Pradesh is one of the biggest states for rice production, with 5.86 million hectares under cultivation and a yield of 15.54 million tonnes ha^{-1}. (2018-19 Report of the Directorate of Economics and Statistics). Improving crop productivity along with soil health is critical for sustainable rice production. However, improper use of establishment methods and imbalance nutrient management can lead to a decline soil health, which can have negative effects on crop yield and quality [1]. Therefore, it is essential to improve soil health for sustainable rice production. Sustainable rice production requires adopting conservation tillage practices to minimize soil disturbance and erosion, promoting better soil structure, moisture retention and nutrient availability. Raised beds with furrow irrigation increase water efficiency and maintain an ideal soil moisture balance [2]. Unpuddled transplanted rice, which avoids traditional flooding and tilling, conserves water, energy and minimizes soil compaction. This method enhances nutrient uptake efficiency and increases soil health making it a promising option for sustainable rice production [3]. Integrated Nutrient Management (INM) is another critical aspect of promoting soil health in rice cultivation. Imbalanced application of chemical fertilizers can lead to soil degradation and nutrient imbalances. To mitigate these issues, INM involves a combination of organic and inorganic fertilizers tailored to meet the specific nutrient requirements of the soil and crop. By incorporating farm yard manure, along with judicious use of chemical fertilizers, improve soil fertility, microbial activity and overall soil health [4]. This approach also contributes to reduced environmental pollution and enhances the sustainability of rice production systems.

2. MATERIALS AND METHODS

2.1 Experiment Details

The field experiment was conducted at Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut (U.P.), during kharif season (2019-2020). It was laid out in split plot design with three replications. The treatments comprised of four planting techniques viz. (M1-Reduced Tillage-Transplanted Rice (RT-TPR), M2-Conventional Tillage-Transplanted Rice (CT-TPR), M3-Furrow Irrigated Raised Beds (FIRB), M4-Unpuddled-Transplanted Rice (UP-TPR)) as main plot treatments and six fertility levels viz (S1-Control, S2-100% NPK Chemical fertilizer, S3-100% N (FYM), S4-50% NPK + 50% N (FYM), S5-75% NPK + 25% N (FYM), S6-100% NPK + 25% N(FYM)) as subplot treatments and rice variety PB1 was tested. The soil of experimental site was low in organic carbon (0.42 %), nitrogen (195.3 kg ha^{-1}) and medium in available phosphorus (12.4 kg ha^{-1}) and available potassium (118.2 kg ha^{-1}) and alkaline in reaction.

2.2 Separation of Soil Aggregates

Soil samples were collected from multiple locations within each plot at two depths (0-15 and 15-30 cm) and combined to create composite samples. These samples were air dried, and larger clods were crushed and sieved to obtain soil particles larger than 5-8 mm. For wet sieving analysis, 100 g of soil passed through a 5-mm sieve and was separated into four aggregate size classes: coarse macroaggregate (>2.0 mm), mesoaggregate (2.0-0.25 mm), microaggregate (0.25-0.05 mm), and 'silt + clay' sized fractions (0.05 mm) using the wet sieving method (Yoder, 1936). Water stable aggregates were determined for one sample, while the other was dispersed with 0.5 percent (w/v) sodium hexametaphosphate in a 1:3 (soil: solution) ratio, followed by mechanical stirring and vertical oscillation. After drying, water stable aggregates and primary particles of various sizes were collected and weighed separately. These metrics represented the aggregation status after adjusting for sand content.

2.3 Particulate Organic Carbon (POC)

To encourage aggregate slaking, 50 g of air-dried soil sample was soaked in deionized water for 30 minutes. The slurry was placed onto a 250µm sieve within a cylinder and shaken at 120rpm with 50 glass beads of 10-mm diameter. Microaggregates passing through the 250 µm filter were collected in a 25µm bottom sieve. The material retained on the 250µm sieve was termed coarse POM, consisting of coarse material (POM and sand from 250 to 2,000 µm). To separate the fine POM, aggregates retained on the 25µm sieve (sized from 25 to 250 µm) were shaken for 18 hours with 25 ml of 0.5 g l^{-1} sodium hexametaphosphate and 12 glass beads of 4-mm diameter [5].

2.4 Total Organic Carbon (TOC)

TOC content was determined by using Walkley and Black's (1934) rapid titration method and computed using Eq. (1):

$$\text{TOC stock (Mg C ha}^{-1}) = \text{TOC content (g C kg}^{-1}) \times \text{BD (Mg m}^{-3}) \times \text{Soil layer (m)} \times 10 \qquad (1)$$

Where, BD is bulk density of the particular soil layer (BD values for 0-5 cm and 5-15 cm soil layer were 1.32 and 1.34 Mg m^{-3}, respectively).

2.5 Microbial Biomass Carbon (MBC)

Calculate soil microbial biomass by incubating soil samples at 25°C for 7 days in the dark, followed by separation into fumigated and nonfumigated subsamples. Soil moisture was adjusted to 55 percent of field water capacity. For MBC, 30 g dry weight soil samples were fumigated with CHCl3 for 24 hours at 25 °C. After removing CHCl3, samples were incubated at 25 °C for 10 days in sealed Mason jars with vials containing 1.0 ml 2 M NaOH. CO2-C flush emitted during fumigation was determined by HCl titration [6].

The MBC was computed using Eq. (2):

$$\text{MBC (mg kg}^{-1}) = (\text{Fc-UFc})/\text{Kc} \qquad (2)$$

Where, Fc is CO2 evolved from the fumigated soil, UFc is CO2 evolved from the unfumigated soil, and Kc is a factor with value of 0.41 Anderson and Domsch, (1978).

For MBN, fumigated and non-fumigated soil samples after 10-day incubation were extracted with 2 M KCl (5:1 ratio of extractant: soil) for 1 h and inorganic N was determined by the Kjeldahl distillation as described by Keeney and Nelson (1982).

The MBN was computed using Eq. (3):

$$\text{MBN (mg kg}^{-1}) = (\text{Fn-UFn})/\text{Kn} \qquad (3)$$

Where, Fn is mineral N from fumigated soil, UFn is mineral N from unfumigated soil, and Kn is a factor with value of 0.57 [7].

2.6 Statistical Analysis

Collected data were analyzed with r programme for descriptive statis tical analysis (Mean and Stander Error of Mean), where the mean differences were adjudged with Duncan's Multiple Range Test (DMRT).

3. RESULTS AND DISCUSSION

3.1 Soil PH & EC

The soil Ph & EC (Table 1) was not significantly influenced by planting techniques and fertility levels. Among the different fertility levels, the highest and lowest values of soil pH & EC were observed with S_2 (100% RDF) and Control treatment, respectively.

3.2 Aggregate Size Distribution

The data (Fig. 1) illustrates aggregate size distribution in different treatments at varying soil depths. At the 0 to 10 cm depth, FIRB treatment had the highest macro-aggregates (>2mm) at 6.25%, followed by RT-TPR (5.5%), UP-TPR (3.5%), and CT-TPR (2.43%). Conversely, CT-TPR had the highest micro-aggregates (<0.25mm) at 84.75%, followed by UP-TPR (48.01%), RT-TPR (57%), and FIRB (41.64%). Similar trends were observed at the 10 to 20 cm depth, with FIRB having the highest macro-aggregates (6.51%), and CT-TPR maintaining the highest micro-aggregates (98.73%). At 20 to 30 cm depth, FIRB showed the highest macro-aggregates (6.68%), and CT-TPR had the highest micro-aggregates (95.86%). Indicating the effectiveness of the practices employed in FIRB cultivation, such as raised bed formation and furrow irrigation. These practices likely encouraged the formation and stability of larger soil aggregates, leading to the observed results. Similar results found by Naresh et al. [8]. CT-TPR plots had the highest percentage of micro-aggregates among the planting techniques, the tillage operations might have broken down larger aggregates into smaller particles, leading to the prevalence of micro-aggregates in the soil. The consistent trends observed at different soil depths suggest that these practices have a lasting impact on soil structure and aggregate formation, similar findings also reported by Jat et al. [9].

3.3 Particulate Organic Carbon

Results (Table 2) indicate significant differences in POC content due to planting techniques and fertility levels. At 0-5 cm depth, M1 RT-TPR showed the highest POC content (1009 mg kg^{-1}), followed by M3 FIRB-TPR (992 mg kg^{-1}), M4 Unpuddled-TPR (938 mg kg^{-1}), and M2 CT-TPR (766 mg kg^{-1}). Deeper at 5-15 cm, M1 RT-TPR again had the highest POC (634 mg kg^{-1}), followed by M3 FIRB-TPR (623 mg kg^{-1}), M4 Unpuddled-TPR (589 mg kg^{-1}), and M2 CT-TPR (481 mg kg^{-1}). The highest POC content was consistently under M1 RT-TPR, likely due to reduced soil disturbance and slower organic matter mineralization, aligning with [10]. CT-TPR exhibited the lowest POC content, likely due to intense conventional tillage. Fertility levels also influenced POC content. At 0-5 cm, S3 100% N (FYM) had the highest POC (1042 mg kg^{-1}), followed by S4 50% NPK + 50% N (FYM) (982 mg kg^{-1}), and S5 75% NPK + 25% N (FYM) (907 mg kg^{-1}). At 5-15 cm, S3 100% N (FYM) again showed the highest POC (659 mg kg^{-1}), followed by S4 50% NPK + 50% N (FYM) (617 mg kg^{-1}), and S5 75% NPK + 25% N (FYM) (570 mg kg^{-1}). Organic fertilizer application (FYM) consistently increased POC content compared to chemical fertilizer (S2) or no fertilizer (S1) even at deeper soil levels. Treatment RT-TPR and organic fertilizer application (FYM) significantly enhance soil POC content, emphasizing the importance of reduced soil disturbance and organic matter addition. Similar findings were reported by Nisar and Benbi [11].

3.4 Total Organic Carbon

Results (Table 2) showed that M1 RT-TPR had the highest TOC content at both depths, with values of 22 g kg^{-1} at 0-5 cm and 16 g kg^{-1} at 5-15 cm. M3 FIRB-TPR also had relatively high TOC levels, with values of 21 g kg^{-1} and 16 g kg^{-1} at the respective depths. In contrast, M2 CT-TPR and M4 Unpuddled-TPR had slightly lower TOC values. Reduced tillage, M1 RT-TPR, led to higher total organic carbon (TOC) content compared to other methods.

Reduced tillage minimizes soil disturbance, preserving organic matter and preventing decomposition. In contrast, conventional tillage (M2) results in lower TOC content due to intensive soil disturbance and accelerated organic matter decomposition. Fertility level S3 (100% N (FYM)) exhibited the highest TOC content at both depths, with values of 24 g kg^{-1} at 0 to 5 cm and 18 g kg^{-1} at 5 to 15 cm. S4 (50% NPK Chemical Fertilizer + 50% N (FYM)) and S5 (75% NPK Chemical Fertilizer + 25% N (FYM)) also showed higher TOC content compared to S1 (Control) and S2 (100% NPK Chemical Fertilizer). S6 (100% NPK Chemical Fertilizer + 25% N (FYM)) had TOC levels similar to the control (S1). Organic manure, particularly farmyard manure, enriches soil with organic carbon, enhancing TOC content. Similar findings were reported by Dutta et al. [12].

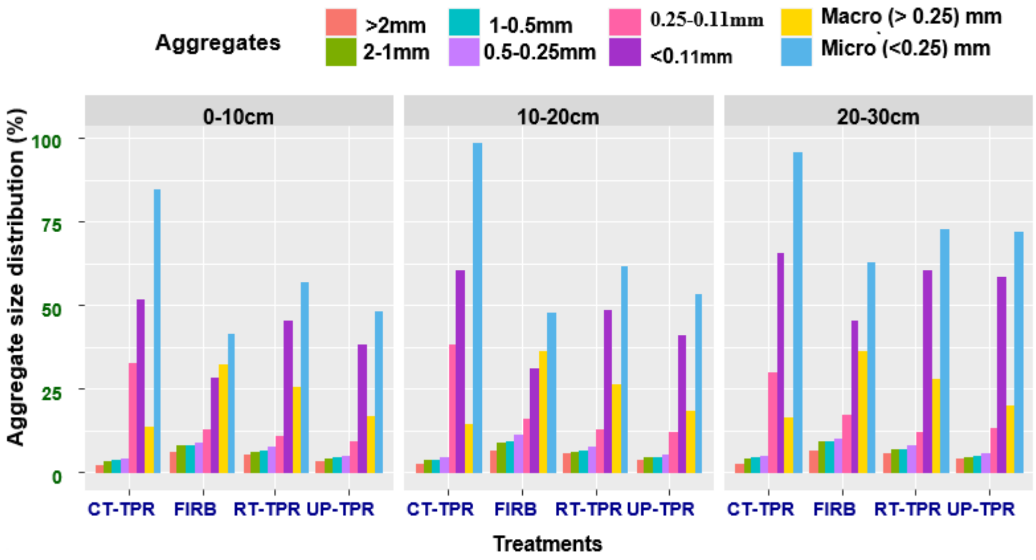

Fig. 1. Effect of planting techniques on soil aggregates distribution

Table 1. Effect of planting techniques, fertility levels on soil pH & EC

Treatment	Soil pH	Soil EC (ds/m)
Planting Techniques		
M_1 RT- TPR	7.5a	0.25a
M_2 CT- TPR	7.5a	0.24a
M3 FIRB - TPR	7.4a	0.25a
M_4 Unpuddled -TPR	7.5a	0.23a
Fertility Levels		
S_1 Control	7.25a	0.23a
S_2 100% NPK Chemical fertilizer	7.87a	0.26a
S3 100% N (FYM)	7.22a	0.24a
S_4 50% NPK + 50% N(FYM)	7.42a	0.24a
S_5 75% NPK + 25% N(FYM)	7.57a	0.25a
S_6 100% NPK + 25% N(FYM)	7.72a	0.25a

Means with the same letter are not significantly different

Table 2. Effect of planting techniques, fertility levels on POC, TOC and MBC of soil

Treatment	POC (mg kg^{-1})		TOC (g kg^{-1})		MBC (mg kg^{-1})	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
Planting techniques						
M_1 RT-TPR	1009a	634a	22a	16a	387a	317a
M_2 CT- TPR	766c	481c	16c	12c	293c	240c
M_3 FIRB - TPR	992a	623a	21a	16a	380a	311a
M_4 Unpuddled -TPR	938b	589b	20b	15b	359b	293b
Fertility levels						
S_1 Control	872b	548c	19d	14d	334c	274c
S_2 100% NPK Chemical fertilizer	887b	558c	19d	14d	340c	279c
S_3 100% N (FYM)	1042a	659a	24a	18a	402a	332a
S_4 50% NPK + 50% N (FYM)	982a	617b	22b	16b	376b	308b
S_5 75% NPK + 25% N (FYM)	907b	570c	20c	15c	348c	285c
S_6 100% NPK + 25% N(FYM)	859b	540c	19d	14d	329c	270c

Means with the same letter are not significantly different

3.5 Microbial Biomass Carbon

MBC (Table 2) values at 0 to 5 cm and 5 to 15 cm depths were determined for different planting techniques and fertility levels (Table 2). M1 (RT-TPR) exhibited the highest MBC values at both depths, with 387 mg kg^{-1} at 0 to 5 cm and 317 mg kg^{-1} at 5 to 15 cm, indicating the positive impact of reduced tillage on soil microbial biomass carbon content. In contrast, M2 (CT-TPR) had the lowest MBC values at both depths (293 mg kg^{-1} at 0 to 5 cm and 240 mg kg^{-1} at 5 to 15 cm), suggesting that traditional tillage methods can adversely affect soil microbial biomass carbon concentration due to extensive soil disturbance, as noted by Yadav et al. [13]. Treatment M3 (FIRB-TPR) and M4 (Unpuddled-TPR) showed intermediate MBC values, indicating a moderate influence on soil microbial biomass carbon content. Regarding fertility levels, the addition of farmyard manure (FYM) significantly enhanced soil MBC compared to chemical fertilizer alone (S2-100% NPK Chemical fertilizer). S3 (100% N (FYM)) had the highest MBC values at both depths (402 mg kg^{-1} at 0 to 5 cm and 332 mg kg^{-1} at 5 to 15 cm), demonstrating the positive impact of completely replacing chemical fertilizer with organic manure on soil microbial biomass carbon. S4 (50% NPK + 50% N (FYM)), S5 (75% NPK + 25% N (FYM)), and S6 (100% NPK + 25% N (FYM)) showed higher MBC values than the control (S1) and chemical fertilizer alone (S2) but lower than those of S3. The control (S1) had the lowest MBC values, indicating the detrimental effect of the absence of fertilizers or amendments on soil microbial biomass carbon content. Reduce Tillage-Transplanted Rice (M1) and complete chemical fertilizer substitution with organic manure (S3) significantly influence soil microbial biomass carbon (MBC) content in rice production, emphasizing their role in improving soil health and fertility, consistent with findings by Nayak et al. [14].

4. CONCLUSION

The experiment results indicate that Furrow Irrigated Raised Bed-Transplanted Rice (FIRB-TPR) encouraged the formation of larger macro-aggregates, while Conventional Tillage-Transplanted Rice (CT-TPR) fostered smaller micro-aggregates. Reduced Tillage-Transplanted Rice (RT-TPR) with FYM and chemical fertilizer increased POC and TOC content. In contrast, CT-TPR exhibited lower POC and TOC levels due to intensive soil disturbance. RT-TPR and FYM application enhanced MBC and overall soil health, suggesting their combined use to improve soil conditions in rice cultivation. Further research and long-term monitoring are essential to evaluate the sustainability and enduring effects of these planting techniques and fertility levels on soil health. Continued research and long-term monitoring are crucial to validate the sustainability and lasting effects of these practices on soil quality and agricultural productivity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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